Feasibility and Signal Analysis of DANTE-TSE with Variable Flip Angles for Intracranial Vessel Wall Imaging at 7 Tesla

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Purpose Intracranial vessel wall imaging (IVWI) facilitates research into cerebrovascular disease, especially for the investigation of intravascular plaque deposition. Increased SNR at 7T could benefit high-resolution IVWI. However, novel methods are needed to minimize SAR, for example using small flip angle blood and CSF suppression modules (in contrast to, e.g., inversion methods). Delay alternating with nutation for tailored excitation (DANTE) is a low flip angle method that has been described by Li *et al*. for blood suppression in carotid wall imaging [1] and CSF suppression in spinal cord imaging at 3T [2]. Wang *et al*. recently reported the use of DANTE with a proton-density-weighted TSE with variable flip angles for IVWI at 3T [3]. The DANTE signal for static spins scales with $1-\sqrt{T1/T2}$. The T1 increase and T2 decrease at 7T result in reduced tissue signals, compared to lower field strengths. We investigated additional signal loss due to brain movement and assessed the feasibility of implementing DANTE-prepared T2-TSE with variable flip angles (DANTE-SPACE) at 7T for IVWI.

Background The SPACE sequence itself exhibits a black-blood effect due to the phase spoiling of moving spins in the presence of strong gradients and non-180º refocusing flip angles. This can be further enhanced by the application of a DANTE pulse train preparation. Indeed, if appropriate DANTE parameters are chosen then the signal from slow flowing spins, such as the CSF circulation, can also be suppressed. Using high gradient amplitudes of up to 40mT/m enhances the phase dispersion in blood and CSF voxels, but also introduces signal loss in tissue spins due to brain movement during the cardiac cycle. Here we used uni-directional DANTE modules to compare the signal loss associated with the three principal gradient directions, i.e. along A»P, R»L and H»F. We assessed the brain stem which is known to exhibit motion [4] and white matter areas close to the middle cerebral artery (MCA), a region that is of interest in plaque imaging in IVWI.

Methods *Protocol to assess signal loss:* Three DANTE-SPACE scans were run, with the direction of the DANTE gradient set to each of the three principal axes, at the maximum strength of 40 mT/m (Table 1) and a further scan without DANTE preparation, using exactly the same acquisition parameters, was acquired for signal normalization for comparison with simulations. Scans were acquired on a 7T whole body scanner (Siemens, Erlangen, Germany). SPACE parameters: Matrix=258x190, voxel=1x1x1mm^3, TR/TE=3980/198ms, ETL=118, BW=592Hz/px, GRAPPA=4. DANTE parameters: FA=10º, N=300, τ=1.4ms. The scans were run in four healthy subjects under institutional ethical approval. All datasets were then non-linearly registered to a T2 template. Three ROIs were defined: one in the brain stem and one in white matter close to the MCA on each hemisphere. The signal reduction was defined as the mean voxel signal ratio $\langle S_{DANTE-SPACE}/S_{SPACE}\rangle$, which was then averaged over all subjects. To rule out gradient strength inconsistencies, the protocol was also run in a pork phantom. *Simulations:* Simulations without assumed motion were carried out in Matlab with the above imaging parameters. To address any uncertainty in B1 we simulated flip angles deviating from the desired prescription by ±50%. Also, T1 was varied by ±20%, with T2 fixed at 47ms [5]. *In Vivo IVWI feasibility:* To test the ability of DANTE-SPACE to achieve effective IVWI at 7T a clinically relevant protocol for the investigation of plaque accummulation in the major vessels was implemented with a resolution of $0.5\times0.5\times1mm^3$. Additional minor protocol modifications to the above, including a TR of 2600ms, resulted in a whole brain scan time of 11 minutes. The sequence was run both with and without DANTE preparation in a single subject. The CNR between tissue/lumen and tissue/CSF was calculated in the MCA region.

	$\vec{G}=(G_{A\gg P},G_{R\gg L},G_{H\gg F})$ $[mT/m]$		
	$(40,0,0)$	$(0,40,0)$	$(0,0,40)$
Brain stem	0.63 ± 0.02	0.64 ± 0.05	0.47 ± 0.07
MCA right	0.75 ± 0.03	0.71 ± 0.04	0.69 ± 0.02
MCA left	0.72 ± 0.02	0.67 ± 0.01	0.64 ± 0.05

Table 1: Signal loss $\langle S_{DANTE-SPACE}/S_{SPACE}\rangle$ along the three principal axes. The variations with different directions imply signal loss due to movement in the specific tissue region.

	$CNR_{tissue/lumen}$	$CNR_{tissue/CSF}$
DANTE-SPACE	14	9
SPACE	18	-10

Table 1: CNR between tissue/lumen and tissue/CSF with and without DANTE preparation. Values are based on ROIs in figure 2d/e.

Results *Signal loss analysis and simulations:* The signal loss in the pork phantom was found to differ by less than 1% among all gradient directions and agreed well with the motion-free simulations. The simulated signal reduction for white matter is shown in Figure 1. When applied to human subjects we observed substantial signal loss of static tissue for DANTE gradients along the H»F direction, and lower losses along A»P (Table 1). These results suggest that there is tissue signal reduction due to brain movement (most pronounced in the H»F direction) beyond the signal loss that would be predicted by the simulated results (that assume static tissue). Higher B1 values in the brain centre might further add to signal loss. *In Vivo IVWI feasibility:* DANTE-SPACE shows better CSF suppression compared to the unprepared SPACE sequence and yields an inversion of the tissue/CSF contrast in the MCA region, achieving an improvement of ~200%. However the CNR between tissue and lumen is reduced by ~23% (Table 2). Figure 2 shows how DANTE-SPACE improves contrast between the MCA vessel wall and CSF (red arrow).

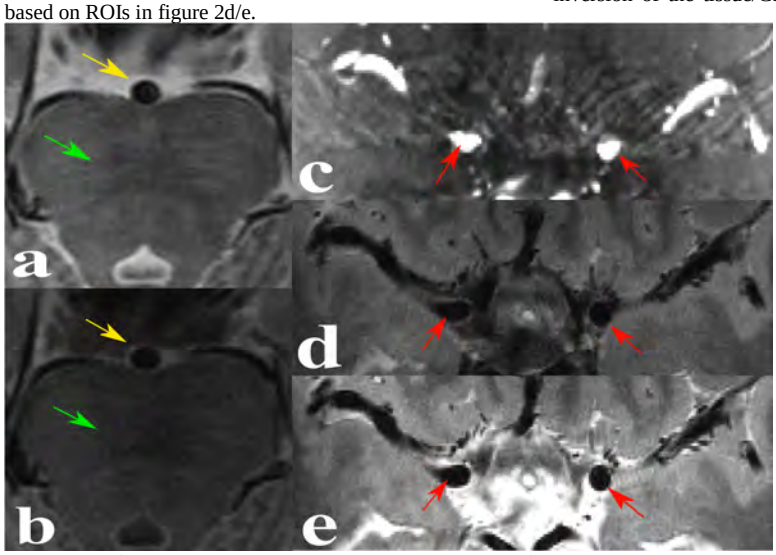

Figure 2. Left: a) SPACE and **b)** DANTE-SPACE images of the brain stem area (green arrow). The basilar artery vessel wall (yellow arrow) is better delineated in the CSF-suppressed DANTE-SPACE image. **Right:** Zoomed MCA region in a Time-of-Flight (c), DANTE-SPACE (d) and SPACE (e) acquisition in the same subject. The red arrows indicate parts of the MCA. The vessel wall is better delineated in DANTE-SPACE (d).

Conclusion The stronger gradient system and T1 increase at 7T benefit blood and CSF suppression in DANTE-SPACE. However, the same phase spoiling mechanism affects the tissue spins which lose signal particulary in the brain stem due to brain movement. The MCA region is less affected. Better contrast between the vessel wall and CSF might aid the identification of plaque accummulation in the wall. CSF suppression should also facilitate the analysis of vessel wall thickening in disease. Future scans in patients with vessel wall pathology will show if DANTE improves the ability to distinguish between plaque, vessel wall and CSF.

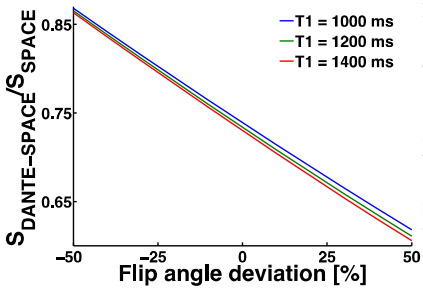

Figure 1: Simulated signal loss $S_{DANTE-SPACE}/S_{SPACE}$ for flip angle deviations due to B1 inhomogeneity and varying T1 values to compare with the measured signals in table 1.

References: [1] Li et al. Radiology 10.1148, 2104. [2] Li et al. Magn Reson Med 2012; 68(5):1423-38. [3]Wang et al. Proc Intl Soc Mag Reson Med 22, 2014. [4] Greitz et al. Neuroradiology 43:370-380, 1992. [5] Cox EF and Gowland PA Magn Reson Med 2010; 64(5):1440-1445.